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著者	安達 文幸
journal or publication title	IEEE Transactions on Vehicular Technology
volume	27
number	4
page range	220-223
year	1978
URL	http://hdl.handle.net/10097/46501

Periodic Switching Diversity Effect on Co-Channel Interference Performance of a Digital FM Land Mobile Radio

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Abstract—The effect of periodic switching diversity on the bit error rate (BER) performance of a binary frequency-shift keying (FSK) system in the presence of co-channel interference is described. The distribution of the signal-to-interference energy ratio per bit presented to the FM detector is found and the diversity effect on the BER performance in a Rayleigh fading environment is analyzed. The diversity effect on the BER performance in a Manchester-coded FSK system with limiter-discriminator detection is verified by laboratory simulation tests using a Rayleigh fading simulator.

I. INTRODUCTION

IN UHF OR microwave land mobile radio communication systems, the same carrier frequency is reused in different radio zones for efficient frequency utilization. Since the signal transmission is usually performed via multiple propagation paths, both desired and interfering signals are subject to Rayleigh fading with vehicle movement [1], [2]. In the presence of fading, the desired signal may fade below the received interfering signal with a high probability, so that the signal transmission performance is severely degraded.

It is well known that diversity techniques are able to improve the co-channel interference performance in a fading signal environment. Many diversity techniques have been proposed and researched [3], [4]. A simple and efficient diversity technique suitable for a digital FM land mobile radio using a binary FSK system with limiter-discriminator detection has been proposed, and its diversity effect on the bit error rate (BER) performance in a Rayleigh fading signal environment has been verified [5]. This technique receives two RF signals periodically by switching two antenna branches at a rate moderately higher than the bit rate (see Fig. 1).

This paper describes the periodic switching diversity effect on the BER performance of a binary frequency-shift keying (FSK) system in the presence of co-channel interference. The distribution of the signal-to-interference energy ratio per bit (SIR) presented to the FM detector is found, and the diversity effect on the BER performance in the presence of co-channel interference is analyzed. Its diversity effect in a Manchester-coded FSK system with limiter-discriminator detection is verified by laboratory simulation tests.

Manuscript received January 3, 1978; revised May 2, 1978.

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II. DIVERSITY EFFECT ON THE BER PERFORMANCE IN THE PRESENCE OF CO-CHANNEL INTERFERENCE

A. Distribution of SIR

The periodic switching diversity strategy is to switch between two RF waves received by the different antenna branches periodically at a rate moderately higher than the bit rate of the binary FSK signal (see Fig. 1). The diversity can change the statistics of the SIR presented to the FM detector. The analysis used in [5] can be also applied to provide the probability density function (pdf) of the SIR.

Let us assume that a single interferer exists and that both desired and interfering signals exhibit mutually independent slow Rayleigh fadings. When the switching rate is much higher than the bit rate, two RF waves received by the respective diversity antennas are periodically switched and combined in a bit interval. Thus the signal energy ϵ_s and the interference energy ϵ_i in a bit interval, presented to the FM detector, become one half of the sum of the corresponding energies on the respective diversity branches, respectively. We obtain

$$\begin{aligned}\epsilon_s &= \epsilon_{s1} + \epsilon_{s2} \\ \epsilon_i &= \epsilon_{i1} + \epsilon_{i2}\end{aligned}\quad (1)$$

where ϵ_{sn} and ϵ_{in} are the signal energy and the interference energy, in a bit interval, on the n th branch ($n = 1, 2$), respectively. Following the result in [5], the joint pdf of ϵ_s and ϵ_i , $p(\epsilon_s, \epsilon_i)$, is given by

$$\begin{aligned}p(\epsilon_s, \epsilon_i) &= \frac{1}{E_s E_i |k|^2} [e^{-\{2\epsilon_s/E_s(1+|k|)\}} \\ &\quad - e^{-\{2\epsilon_s/E_s(1-|k|)\}}] \\ &\quad \cdot [e^{-\{2\epsilon_i/E_i(1+|k|)\}} - e^{-\{2\epsilon_i/E_i(1-|k|)\}}]\end{aligned}\quad (2)$$

where E_s and E_i are the average signal energy and the average interference energy on each branch, respectively, and k is the complex fading correlation coefficient between the two diversity branches. The complex fading correlation coefficient is related to the envelope correlation coefficient ρ . ρ is very nearly equal to $|k|^2$ [2]. Therefore, defining the SIR presented to the FM detector as $\lambda = \epsilon_s/\epsilon_i$, the pdf of λ , $p(\lambda)$, is easily

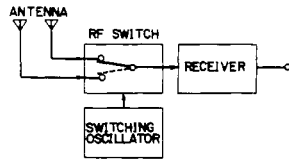


Fig. 1. Periodic switching diversity.

derived from (2):

$$p(\lambda) = \frac{\Lambda}{4|k|^2} \{2(1 + |k|^2)(\Lambda + \lambda)^{-2} - (1 - |k|^2)^2 [\{\Lambda(1 - |k|) + \lambda(1 + |k|)\}^{-1} + \{\Lambda(1 + |k|) + \lambda(1 - |k|)\}^{-1}]\} \quad (3)$$

where $\Lambda = E_s/E_i$ is the average SIR on each branch.

B. BER Performance

With one crucial but not unreasonable assumption, a deceptively simple form may be obtained for the BER performance on the basis of the FM capture effect. Let us assume the following. No error can occur as long as the signal energy e_s presented to the FM detector does not fade below the interference energy e_i presented to the FM detector, i.e., $\lambda \geq 1$. If e_s fades below e_i , i.e., $\lambda < 1$, errors occur with probability 1/2. Let us denote the BER by $P_e(\Lambda)$ when the average SIR on each branch is Λ . From the above assumption, the BER is equal to one half of the cumulative probability at $\lambda = 1$:

$$P_e(\Lambda) = \frac{1}{2} \int_0^1 p(\lambda) d\lambda. \quad (4)$$

Substituting (3) into (4), we obtain

$$P_e(\Lambda) = \frac{3\Lambda + 1 + |k|^2(\Lambda - 1)}{2(\Lambda + 1)[(\Lambda + 1)^2 - |k|^2(\Lambda - 1)^2]}. \quad (5)$$

For $k = 1$, (5) reduces to the BER without diversity:

$$P_e(\Lambda) = \frac{1}{2} \cdot \frac{1}{(\Lambda + 1)}. \quad (6)$$

Comparing (5) with (6), it is found that the periodic switching diversity can improve the co-channel interference performance.

C. Comparison

We compare the periodic switching diversity with the well-known selection and maximal-ratio combinings with uncorrelated two branch signals. There are several methods of instrumenting the selection and maximal-ratio combiners [4]. For the selection combiner, we consider two methods: the total-power method, which selects the branch with the larger total-power (desired signal power plus interference power), and the desired-signal-power method, which selects the branch with the larger desired signal power. For the maximal-ratio combiner, we also consider two methods: the perfect-pilot

method, which adjusts the branch gains to be equal to the complex conjugate of the desired signal pilot phasor, and the separate-pilot method, which adjusts the branch gains to be equal to the complex conjugate of the sum of the desired signal pilot phasor and the interferer pilot phasor.

Bond and Meyer [6] have derived the probability distribution of the SIR λ for the selection combining using the total-power method. The probability distributions of λ for the selection combining using the desired signal power method and for the maximal-ratio combining are derived in [7]. Remember that the BER $P_e(\Lambda)$ is equal to one half of the cumulative probability at $\lambda = 1$ as shown in (4). For the selection combining, we obtain

$$P_e(\Lambda) = \frac{1}{2} \cdot \frac{13\Lambda + 3}{(\Lambda + 1)(\Lambda + 3)(3\Lambda + 1)}, \quad \text{for the total-power method} \quad (7)$$

and

$$P_e(\Lambda) = \frac{1}{(\Lambda + 1)(\Lambda + 2)}, \quad \text{for the desired-signal-power method.} \quad (8)$$

For the maximal-ratio combining, we obtain

$$P_e(\Lambda) = \frac{1}{2} \cdot \frac{1}{(\Lambda + 1)^2}, \quad \text{for the perfect-pilot method} \quad (9)$$

and

$$P_e(\Lambda) = \frac{1}{2} \cdot \frac{3\Lambda + 1}{(\Lambda + 1)^3}, \quad \text{for the separate-pilot method.} \quad (10)$$

By comparing (5) with (7)–(10), it is found that the performance of the periodic switching diversity is just the same as that of the maximal-ratio combining using the separate-pilot method. Equations (5)–(10) are plotted in Fig. 2.

III. EXPERIMENTAL PROCEDURE

A block-diagram of the laboratory simulation test system is shown in Fig. 3.

A. Transmitter

Both desired and interfering modulating signals are mutually independent 511-bit pseudonoise (PN) sequences with a bit rate of $f_b = 600$ bit/s. In an each encoder, after being differentially encoded, the above PN sequence is transformed into a Manchester-coded data signal. Then each 900-MHz band carrier is frequency modulated with the Manchester-coded data signal, resulting in a Manchester-coded FSK signal equivalent to a nonreturn to zero (NRZ) binary FSK signal with a bit rate of 1200 bit/s.

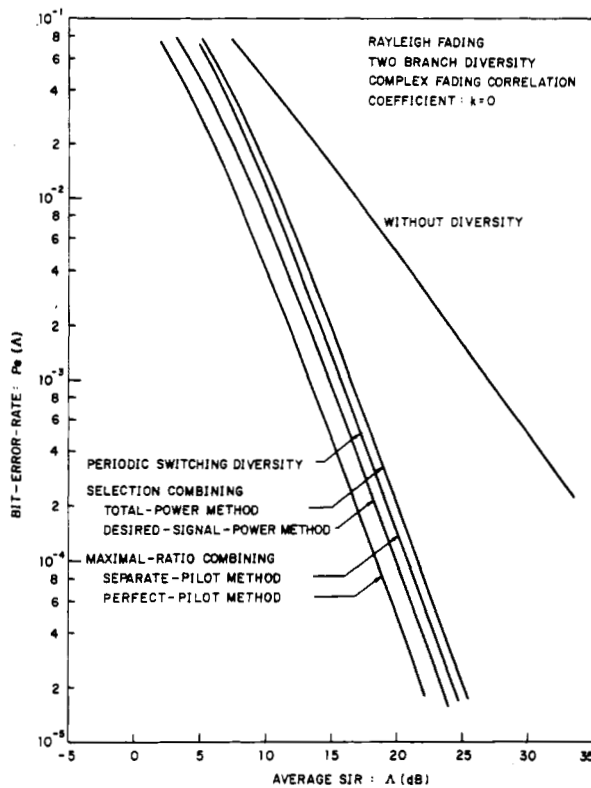


Fig. 2. Comparison between periodic switching diversity and well-known selection and maximal-ratio combinings.

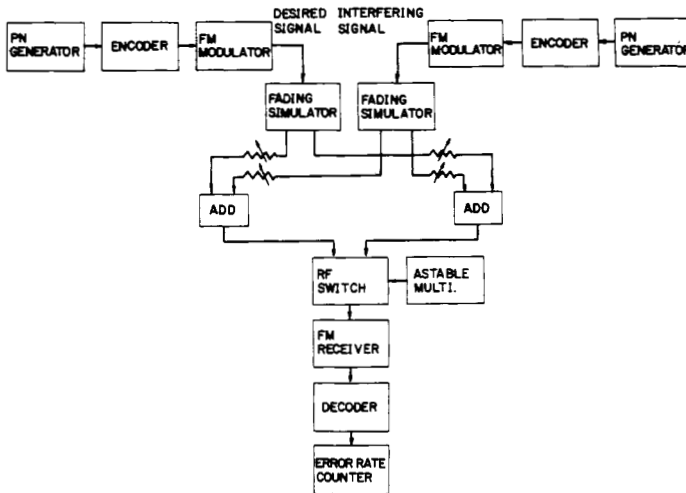


Fig. 3. Laboratory simulation test system.

The carrier frequency separation between the desired signal and interfering signal is set to zero so that an ideal co-channel situation may be studied.

B. Fading Simulation

The two FSK signals are fed to the Rayleigh fading simulators [8], respectively. Each fading simulator provides two transmission paths to simulate the correlation which two fading signals may have at the diversity antennas. The envelope correlation coefficient ρ is variable from 0 to 1 so that the influence of correlation on the diversity effect may be measured. The envelope correlations in the respective fading simulators are chosen to be equal to each other. The fading of the desired signal is independent of that of the interfering signal.

C. Receiver

The receiver consists of an RF switch unit, an FM receiver, and a decoder. The RF switch unit consists of a p-i-n diode switch and an astable multivibrator with adjustable free running frequency. The FM receiver is a conventional double conversion type using a limiter-discriminator. Two Butterworth crystal filters are used as the first and second IF filters of this FM receiver. Overall 3-dB predetection bandwidth is 16 kHz.

The decoder is composed of a postdetection filter, a timing recovery circuit, decision circuit, and a difference-logic circuit. The post detection filter is a Gaussian-type active filter with 3-dB bandwidth of 626 Hz. The timing recovery circuit is composed of a digital phase-locked loop with timing error smaller than ± 9 degrees. The postdetection filter output is decided upon as "mark" or "space" by the decision circuit. After being differentially decoded by the difference-logic circuit, the BER is measured by the error rate counter.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The BER performance was measured for a typical vehicle speed of 48 km/h, and the average carrier-to-noise ratio (CNR) on each diversity branch of 45 dB. In the following measurements, the SIR on the two diversity branches were equal to each other, and the frequency deviation of the desired signal Δf_s , and that of the interfering signal Δf_i , were chosen as $\Delta f_s = \Delta f_i = \pm 5$ kHz.

A. Optimum Switching Rate

Fig. 4 shows the measured BER as a function of the switching rate f_s for the envelope correlation of $\rho = 0$. The results indicate that the measured BER decreases, then increases again as the switching rate increases to an excessively high switching rate. Therefore, there exists an optimum value in the switching rate. A possible explanation for the BER increase at high switching rate is as follows [5]: when the switching rate is excessively high, the spectrum of the IF filter input is so spread that the signal distortion is caused by IF filter band restriction. Thus in the following measurements the switching rate was chosen to be the optimum value of $f_s = 2$ kHz.

B. Measured BER Performance

Fig. 5 shows the measured BER performance with the envelope correlation coefficient ρ as a parameter. Although differential encoding is used in the laboratory simulation test, each measured BER value should be equal to the theoretical value predicted in Section II because we assume that errors occur with probability 1/2 when the signal energy fades below the interference energy. For comparison, the theoretical BER performances are plotted as solid curves. Reasonably good agreement is obtained.

V. CONCLUSION

This paper describes the improvement made by periodic switching diversity on the co-channel interference performance of a binary FSK system with limiter-discriminator detection and Rayleigh fading. The distribution of the SIR presented to

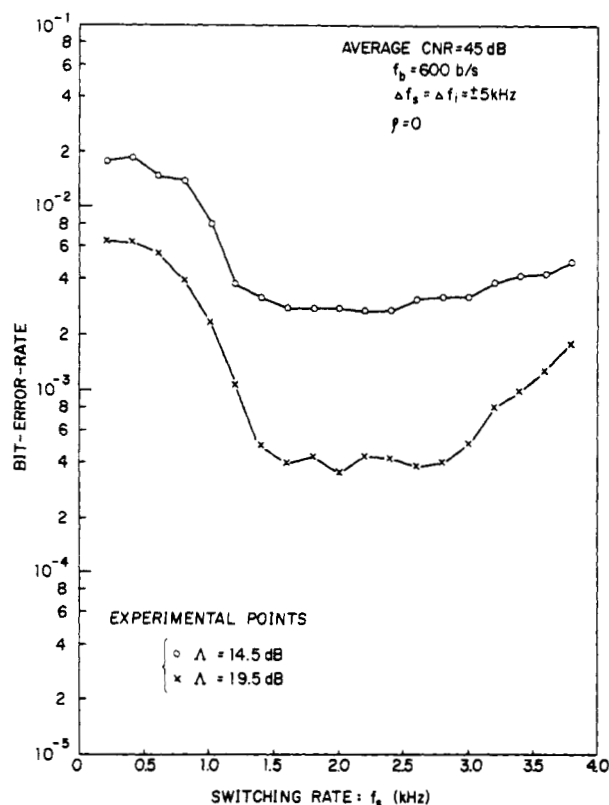


Fig. 4. Bit error rate versus switching rate with average SIR as parameter.

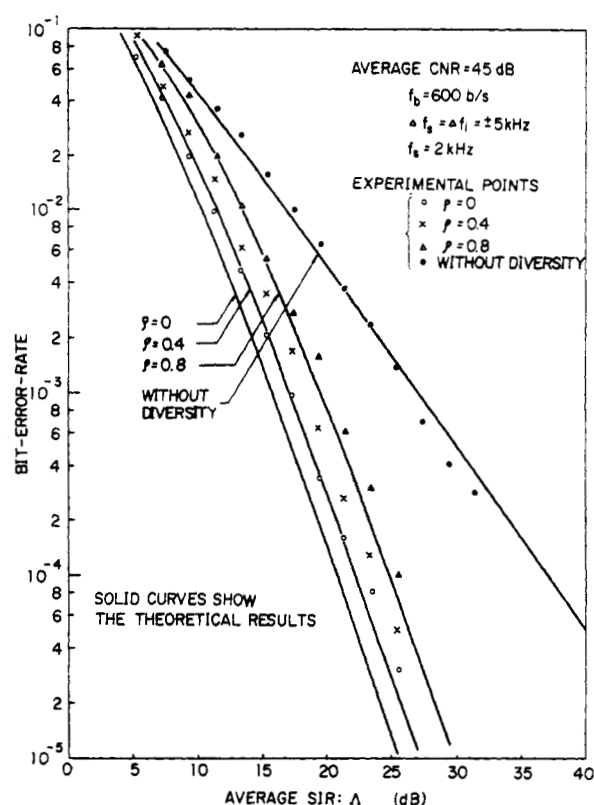


Fig. 5. Bit error rate versus average SIR with ρ as parameter.

the FM detector is found and the diversity effect on the BER performance in a Rayleigh fading environment is analyzed. The experimental verification by the laboratory simulation tests is also presented.

The ability to combat the co-channel interference has been surely verified. However, the adjacent-channel interference performance may be degraded because periodically switching the RF stage would tend to cause the adjacent-channel spectrum to fold over into the desired channel band unless adjacent-channel selectivity is provided before switching.

ACKNOWLEDGMENT

The author wishes to thank Mr. S. Ito, Chief of Mobile Radio Communication System Section and Mr. K. Hirade, Staff Engineer of Mobile Radio Communication Equipment Section for their useful discussions.

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Fumiyuki Adachi for a photograph and biography see page 219 of this issue.